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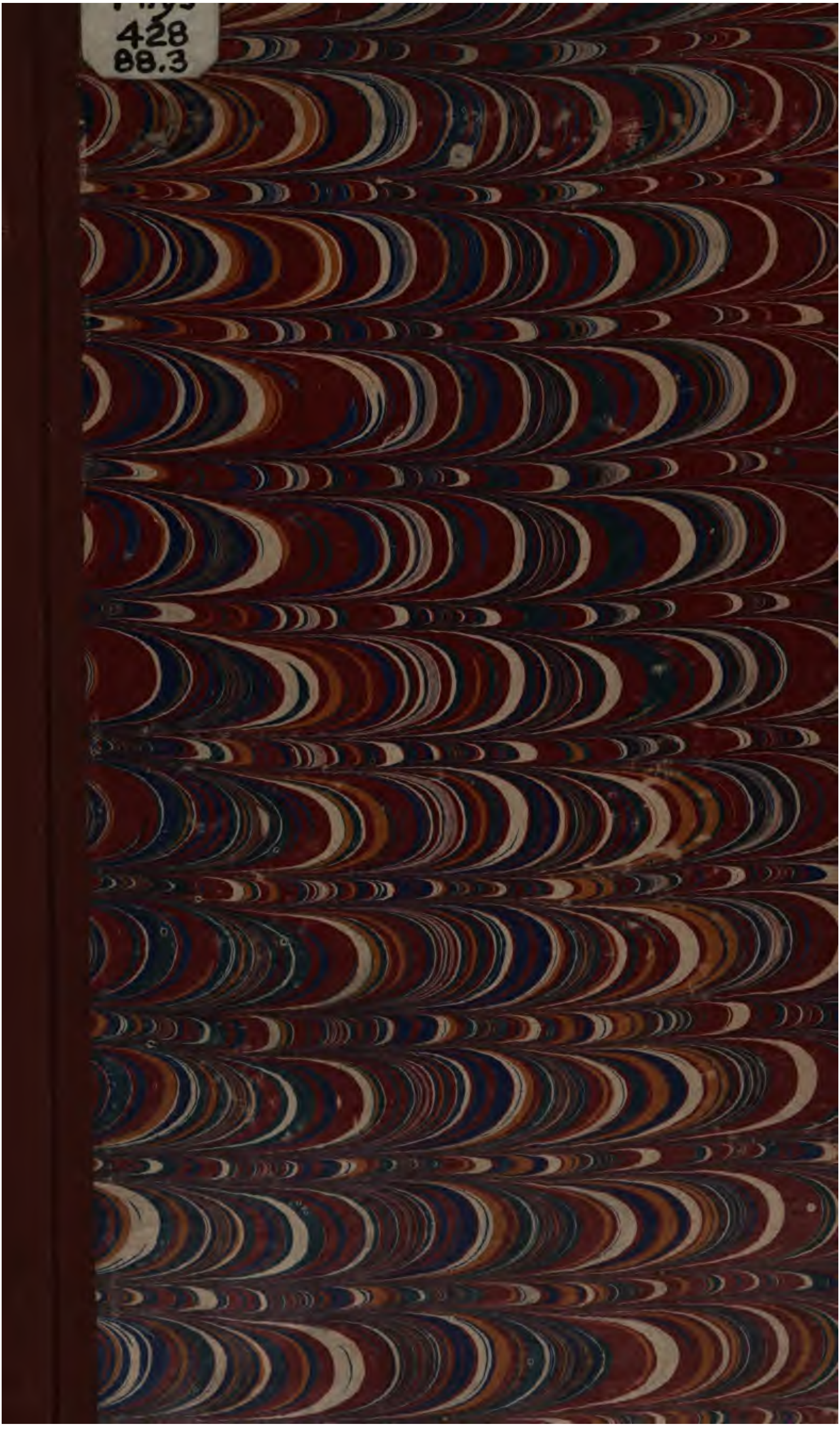

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FROM

William Harkness

1 July, 1891.

With the compliments of Wm. Harkness,
U. S. Naval Observatory, Washington, D. C.

ON

THE PROGRESS OF SCIENCE

AS EXEMPLIFIED IN

THE ART OF WEIGHING AND MEASURING;

BEING

THE PRESIDENTIAL ADDRESS DELIVERED BEFORE THE
WASHINGTON PHILOSOPHICAL SOCIETY,
DECEMBER 10, 1887,

BY

WM. HARKNESS,

TO WHICH ARE APPENDED

SOME HISTORICAL NOTES

AND

A BIBLIOGRAPHY.

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BULLETIN

OF THE

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ANNUAL ADDRESS OF THE PRESIDENT.

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ANNUAL ADDRESS OF THE PRESIDENT,

WILLIAM HARKNESS.

Delivered December 10, 1887.

THE PROGRESS OF SCIENCE AS EXEMPLIFIED IN THE ART OF WEIGHING AND MEASURING.

Two centuries ago the world was just beginning to awaken from an intellectual lethargy which had lasted a thousand years. During all that time the children had lived as their parents before them, the mechanical arts had been at a standstill, and the dicta of Aristotle had been the highest authority in science. But now the night of mediævalism was approaching its end, and the dawn of modern progress was at hand. Galileo had laid the foundation for accurate clocks by discovering the isochronism of the simple pendulum; had proved that under the action of gravity light bodies fall as rapidly as heavy ones; had invented the telescope and with it discovered the spots on the sun, the mountains on the moon, the satellites of Jupiter, and the so-called triple character of Saturn; and after rendering himself immortal by his advocacy of the Copernican system, had gone to his grave, aged, blind, and full of sorrows. His contemporary, Kepler, had discovered the laws which, while history endures, will associate his name with the theory of planetary motion, and he also had passed away. The first Cassini was still a young man, his son was a little child, and his grandson and great-grandson, all of whom were destined to be directors of the Paris Observatory, were yet unborn. The illustrious Huyghens, the discoverer of Saturn's rings and the father of the undulatory theory of light, was in the zenith of his powers. The ingenious Hooke was a little younger, and Newton, towering above them all, had recently invented fluxions, and on the 28th of April, 1686, had presented his Principia to the Royal Society of London and given the theory of gravitation to the world. Bradley, who discovered nutation and the aberration of light; Franklin, the statesman and philosopher, who first drew the lightning from the clouds; Dollond, the inventor of the achromatic telescope; Euler, the mathematician who was destined to accomplish so much in perfecting algebra, the calculus, and the lunar theory; Laplace, the author of the Mécanique Céleste; Rumford, who laid the foundation of the mechanical theory of heat; Dalton, the author of the atomic theory upon which all chemistry rests; and Bessel, the greatest of modern astronomers—these and others almost as illustrious, whom we cannot even name to-night, were still in the womb of time.

Pure science first felt the effects of the new intellectual life and it was more than a century later before the arts yielded to its influence. Then came Hargreaves, the inventor of the spinning-jenny; Arkwright, the inventor of the cotton-spinning frame; Watt, who gave us the condensing steam engine; Jacquard, the inventor of the loom for weaving figured stuffs; Murdock, the originator of gas lighting; Evans, the inventor of the high-pressure steam engine; Fulton, the father of steam navigation; Trevithick, who ranks very near Watt and Evans in perfecting the steam engine; and Stephenson, the father of railroads. If now we add the names of those who have given us the telegraph, to wit: Gauss, the eminent physicist and the greatest mathematician of the present century; Weber, Wheatstone, and Henry—all famous physicists—and Morse, the inventor and engineer; we have before us the demi-gods who have transformed the ancient into the modern world, given us machinery which has multiplied the productive power of the human race many fold, annihilated time and space, and bestowed upon toiling millions a degree of comfort and luxury which was unknown to kings and emperors of old.

The discoveries and inventions of the last two centuries have so far exceeded all others within historic times that we are amply justified in calling this an age of phenomenal progress, and under the circumstances a little self-glorification is pardonable—perhaps even natural. The weekly and monthly records of scientific events which appear in so many newspapers and magazines are the immediate result of this, and the great increase of ephemeral scientific literature has led multitudes of educated people to believe that such records represent actual progress. The multiplication of bricks facilitates the building of houses, but does not necessarily improve architecture. Similarly, the multiplication of minor investigations improves our knowledge of details, but rarely affects the great philosophic theories upon which science is founded. The importance of human actions is measured by the degree in which they affect human thought, and the only way of permanently affecting scientific thought is by modifying or extending scientific theories. The men who do that are neither numerous, nor do they require weekly paragraphs to record their deeds; but their names are honored by posterity. Even in this golden age the advance of science is not steady, but is made by spasmodic leaps and bounds. Mere scientific brick making, commonly called progress, is always the order of the day until some genius startles the world by a discovery affecting accepted theories. Then every effort is directed in the new line of thought until it is measurably worked out, and after that brick making again resumes its place. While the progress in two centuries has been immense, the progress in a week or a month is usually almost nil. Optimism has its uses in many departments of human affairs, but science should be cool and dispassionate, having regard only for the truth. To make a trustworthy estimate of the actual state of the whole vast realm of science would be a task beyond the powers of any one man; but perhaps it will not be amiss to spend the time at our disposal this evening in briefly reviewing the recent progress and present condition of the fundamental processes upon which the exact sciences rest—I allude to the methods of weighing and measuring.

Physical science deals with many quantities, but they are all so related to each other that almost every one of them can be expressed in terms of three fundamental units. As several systems of such units are possible, it is important to select the most convenient, and the considerations which guide us in that respect are the following:

1. The quantities selected should admit of very accurate comparison with other quantities of the same kind.

2. Such comparisons should be possible at all times, and in all places.

3. The processes necessary for making such comparisons should be easy and direct.

4. The fundamental units should be such as to admit of easy definitions and simple dimensions for the various derived units.

Scientific men have long agreed that these requirements are best fulfilled by adopting as the fundamental units, a definite length, a definite mass, and a definite interval of time. Length is an element which can be very accurately measured and copied, but it must be defined by reference to some concrete material standard, as for example, a bar of metal, and as all substances expand and contract with changes of temperature, it is necessary to state the temperature at which the standard is correct. A standard of mass, consisting of a piece of platinum, quartz, or other material not easily affected by atmospheric influences, probably fulfills the conditions set forth above better than any other kind of magnitude. Its comparison with other bodies of approximately equal mass is effected by weighing, and as that is among the most exact of all laboratory operations, very accurate copies of the standard can be made, and they can be carried from place to place with little risk of injury. Time is also an element which can be measured with extreme precision. The immediate instruments of measurement are clocks and chronometers, but their running is checked by astronomical observations and the ultimate standard is the rotation of the earth itself.

It is important to note that the use of three fundamental units is simply a matter of convenience and not a theoretical necessity, for the unit of mass might be defined as that which at unit distance would generate in a material point unit velocity in unit time; and thus we should have a perfectly general system of measurement based upon only two fundamental units—namely, those of space and time. Such a system is quite practicable in astronomy, but cannot yet be applied with accuracy to ordinary terrestrial purposes. According to the law of gravitation

$$\text{Mass} = \text{Acceleration} \times (\text{Distance})^2$$

and as in the case of the earth we can measure the quantities on the right-hand side of that equation with considerable accuracy, we can satisfactorily determine the earth's mass in terms of the supposed unit. That suffices for the needs of astronomy, but for other scientific and commercial purposes a standard of mass having a magnitude of about a pound is necessary, and as two such masses can be compared with each other from five to ten thousand times more accurately than either of them can be determined in terms of the supposed unit, three fundamental units are preferable to two.

The Chaldeans, Babylonians, Persians, Greeks, and Romans all seem to have had systems of weights and measures based upon tolerably definite standards, but after the decline of the Roman Empire these standards seem to have been forgotten, and in the beginning of the sixteenth century the human body had so far become the standard of measurement that the units in common use, as for example, the foot, palm, etc., were frequently taken directly from it. The complete table of measures of length was then as follows: the breadth (not the length) of four barley corns make a digit, or finger breadth; four digits make a palm, (measured across the middle joints of the fingers;) four palms are one foot; a foot and a half is a cubit; ten palms, or two feet and a half, are a step; two steps, or five feet, are a pace; ten feet are a perch; one hundred and twenty-five paces are an Italic stadium; eight stadia, or one thousand paces, are an Italic mile; four Italic miles, are a German mile; and five Italic miles are a Swiss mile. It was then the practice to furnish standards of length in books by printing in them lines a foot or a palm long, according to the size of the page, and from these and other data it appears that the foot then used on the continent of Europe had a length of about ten English inches.

In England the first attempts at scientific accuracy in matters of measurement date from the beginning of the seventeenth century, when John Greaves, who must be considered as the earliest of the scientific metrologists, directed attention to the difference between the Roman and English foot by tolerably accurate determinations of the former, and also attempted the investigation of the Roman weights. He was followed by Dr. Edward Bernard, who wrote a treatise on ancient weights and measures about 1685, and towards the end of the century the measurements of the length of a degree by Picard and J. D. Cassini awakened the attention of the French to the importance of rigorously exact standards. In considering the progress of science with respect to standards of length we may safely confine our inquiries to the English yard and the French toise and meter, for during the last two hundred years they have been almost the only standards adopted in scientific operations.

The English measures of length have come down from the Saxons, but the oldest standards now existing are the Exchequer yards of

Henry VII (1490)[1] and Elizabeth (1588).[2] These are both brass end measures, the former being an octagonal rod about half an inch in diameter, very coarsely made, and as rudely divided into inches on the right hand end and into sixteenths of a yard on the left hand end; the latter a square rod with sides about half an inch wide, also divided into sixteenths of a yard and provided with a brass bed having end pieces between which the yard fits. One end of the bed is divided into inches and half inches. Francis Baily, who saw this Elizabethan standard in 1836, speaks of it as "this curious instrument, of which it is impossible, at the present day, to speak too much in derision or contempt. A common kitchen poker, filed at the ends in the rudest manner by the most bungling workman, would make as good a standard. It has been broken asunder; and the two pieces have been dove-tailed together: but so badly that the joint is nearly as loose as that of a pair of tongs. The date of this fracture I could not ascertain, it having occurred beyond the memory or knowledge of any of the officers at the Exchequer. And yet, till within the last 10 years, to the disgrace of this country, copies of this measure have been circulated all over Europe and America, with a parchment document accompanying them (charged with a stamp that costs £3. 10s. exclusive of official fees) certifying that they are true copies of the English *standard*."[3]

In the year 1742 certain members of the Royal Society of London, and of the Royal Academy of Sciences of Paris, proposed that, in order to facilitate a comparison of the scientific operations carried on in the two countries, accurate standards of the measures and weights of both should be prepared and preserved in the archives of each of these societies. This proposition having been approved, Mr. George Graham at the instance of the Royal Society had two substantial brass rods made, upon which he laid off, with the greatest care, the length of three English feet from the standard yard kept at the Tower of London. These two rods, together with a set of troy weights, were then sent over to the Paris Academy, which body, in like manner, had the measure of a French half toise set off upon the rods, and keeping one, as previously agreed, returned the other, together with a standard weight of two marcs, to the Royal Society. In 1835, Baily declared this copy of the half toise to be of little value because the original toise-étalon was of iron, and the standard temperature in France differed from that in England.[1] In his opinion the French should have sent over an iron half toise in exchange for the English brass yard; but this criticism loses much of its force when it is remembered that in 1742 neither England nor France had fixed upon a temperature at which their standards were to be regarded as of the true length. On the return of the rod from Paris Mr. Graham caused Jonathan Sisson to divide the English yard and the French half toise each into three equal parts, after which the rod was deposited in the archives of the Royal Society, where it still remains.[2] Objection having been made that the original and legal standard yard of England was not the one at the Tower, but the Elizabethian standard at the Exchequer, the Royal Society requested Mr. Graham to compare his newly-made scale with the latter standard, and on Friday, April 22, 1743, he did so in the presence of a committee of seven members of the Royal Society. In the following week the same gentlemen compared the Royal Society's scale with the standards at Guildhall and the Tower, and also with the standard of the Clockmakers' Company. These comparisons having shown that the copy of the Tower yard upon the Royal Society's scale was about 0·0075 of an inch longer than the standard at the Exchequer, Mr. Graham inscribed upon the Royal Society's scale a copy of the latter standard also, marking it with the letters Exch., to distinguish it from the former, which was marked E. (English), and from the half toise which was marked F. (French).[3]

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[1] 43, p. 34, and 44, pp. 51–2. (See Bibliography on page lxxix.)

[2] 43, p. 25.

[3] 34, p. 146.

In the year 1758 the House of Commons appointed a committee to inquire into the *original* standards of weights and measures of England; and, under instructions from that committee, the celebrated instrument maker, John Bird, prepared two brass rods, respecting which the committee speak as follows in their report: "And having those rods, together with that of the Royal Society laid in the same place, at the receipt of the Exchequer, all night with the standards of length kept there, to prevent the variation which the difference of air might make upon them, they the next morning compared them all, and, by the means of beam compasses brought by Mr. Bird, found them to agree as near as it was possible."[4] One of these rods was arranged as a matrix for testing end measures, and the other was a line measure which the committee recommended should be made the legal standard of England, and which has since been known as Bird's standard of 1758. Respecting the statement that after lying together all night the rods were *all* found to agree as near as it was possible, Baily says: "This is somewhat remarkable, and requires further explanation, which unfortunately cannot now be accurately obtained. For it is notorious that the measure of the yard of the Royal Society's scale differs very considerably from the standard yard at the Exchequer: * * * Owing to this singular confusion of the lengths of the measures, which does not appear to have been unraveled by any subsequent Committee, it has happened that the Imperial standard yard * * * has been assumed nearly 1 ÷ 140 of an inch longer than the ancient measure of the kingdom."[1] There is little difficulty in surmising what Bird did. The Exchequer standard consisted of a rod and its matrix. The Royal Society's committee assumed the rod to be the true standard of 36 inches, and upon that assumption Graham's measurements gave for the length of the matrix 36·0102 inches, and for the length of the Royal Society's yard 36·0075 inches. The Parliamentary committee of 1758 probably assumed the standard to consist of the rod and matrix together, which seems the better view; and by laying the rod in its matrix and measuring to the joint between them, Bird would have got a length of about 36·0051 inches. The mean between that and 36·0075 would be 36·0063, which differs very little from the length of Bird's standard resulting from Sir George Shuckburgh's measurements. Thus the committee's statement is justified, and there has been no falsification of the ancient standards.

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[1] 34, p. 37. [2] 6, pp. 185–8. [3] 7, pp. 541–556. [4] 11, p. 434.

On December 1, 1758, Parliament created another committee on weights and measures which in April, 1759, repeated the recommendation that Bird's standard of 1758 should be legalized, and further recommended that a copy of it should be made and deposited in some public office, to be used only on special occasions.[2] The copy was made by Bird in 1760, but owing to circumstances entirely unconnected with the subject, no legislation followed for sixty-four years.

The Royal Commission appointed during the reign of George III, to consider the subject of weights and measures, made its first report on June 24, 1819, and therein recommended the adoption of the standard of length which had been used by General Roy in measuring the base on Hounslow Heath;[1] but in a second report made July 13, 1820, they wrote, "We * * * have examined, since our last report, the relation of the best authenticated standards of length at present in existence, to the instruments employed for measuring the base on Hounslow Heath, and in the late trigonometrical operations—But we have very unexpectedly discovered, that an error has been committed in the construction of some of these instruments:[2] We are therefore obliged to recur to the originals which they were intended to represent, and we have found reason to prefer the Parliamentary standard executed by Bird in 1760, which we had not before received, both as being laid down in the most accurate manner, and as the best agreeing with the most extensive comparisons, which have been hitherto executed by various observers, and circulated through Europe; and in particular with the scale employed by the late Sir George Shuckburgh."[3]

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[1] 34, p. 43.

[2] 12, p. 463.

Accordingly, when in 1824 Parliament at length took action, Bird's standard of 1760 was adopted instead of that of 1758. The former being a copy of a copy, its selection as a national standard of length seems so singular that the circumstances which brought about that result should scarcely be passed over in silence. Bird had a very accurate brass scale 90 inches long, which he used in all his dividing operations, whether upon circles or straight lines, and which Dr. Maskelyne said was 0·001 of an inch shorter on three feet than Graham's Royal Society yard E.[4] In the year 1792, or 1793, the celebrated Edward Troughton made for himself a five foot scale, which conformed to Bird's, and which he afterwards used in laying down the divisions of the various instruments that passed through his hands. This was the original of all the standard scales he ever made, and at the beginning of the present century he believed these copies, which were made by the aid of micrometer microscopes, to be so exact that no variations could possibly be detected in them, either from the original or from each other. Among the earliest of the scales so made by Troughton was the one used by Sir George Shuckburgh in 1796–8 in his important scientific operations for the improvement of the standards. Subsequently, the length of the meter was determined by comparison with this scale and with the supposed fac-simile of it made by Troughton for Professor Pictet, of Geneva, and thus it happened that on the continent of Europe all measures were converted into English units by a reference to Sir George Shuckburgh's scale. The Royal Commission of 1819, believed Bird's standard of 1760 to be identical with Shuckburgh's scale, and they legalized it rather than the standard of 1758, in order to avoid disturbing the value of the English yard which was then generally accepted for scientific purposes.

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[1] 23, p. 4. [2] 27, p. 92. [3] 24, p. 3; also, 25 and 26. [4] 13, p. 326.

There are yet four other scales of importance in the history of English standards—namely, the brass five-foot scale made for Sir George Shuckburgh by Troughton in 1796; two iron standard yards, marked 1A and 2A, made for the English Ordnance Survey department by Messrs. Troughton and Simms in 1826–'7, and the Royal Society's standard yard constructed by Mr. George Dollond, under the direction of Captain Henry Kater, in 1831.

Bearing in mind the preceding history, the genesis of the present English standard yard may be thus summarized: In 1742 Graham transferred to a bar made for the Royal Society a length which he intended should be that of the Tower yard, but which was really intermediate between the Exchequer standard yard of Elizabeth and its matrix. That length he marked with the letter E, and, although destitute of legal authority, it was immediately accepted as the scientific standard and was copied by the famous instrument makers of the time with all the accuracy then attainable. Thus it is in fact the prototype to which all the accurate scales made in England between 1742 and 1850 can be traced. Bird's standard of 1758 was compared with the Exchequer standard and with the Royal Society's yard E, and was of a length between the two. Bird's standard of 1760, legalized as the Imperial standard in June, 1824, was copied from his standard of 1758. After becoming the Imperial standard, Bird's standard of 1760 was compared with Sir George Shuckburgh's scale by Captain Kater in 1830 and by Mr. Francis Baily in 1834; with the Ordnance yards 1A and 2A in 1834 by Lieutenant Murphy, R. E., Lieutenant Johnson, R. N., and Messrs. F. Baily and Donkin; and with Kater's Royal Society yard by Captain Kater in 1831. On October 16th, 1834, the Imperial standard (Bird's standard of 1760) was destroyed by the burning of the Houses of Parliament, in which it was lodged, and very soon thereafter the Lords of the Treasury took measures to recover its length. Preliminary inquiries were begun on May 11, 1838, and on June 20, 1843, they resulted in the appointment of a Commission to superintend the construction of new Parliamentary standards of length and weight, among whose members the Astronomer Royal (now Sir George B. Airy), Messrs. F. Baily, R. Sheepshanks, and Prof. W. H. Miller, were prominent. The laborious investigations and experiments carried out by that Commission cannot be described here, but it will suffice to say that for determining the true length of the new standard Mr. Sheepshanks employed a provisional yard, marked upon a new brass bar designated "Brass 2," which he compared as accurately as possible with Sir George Shuckburgh's scale, the two Ordnance yards, and Kater's Royal Society yard. The results in terms of the lost Imperial standard were as follows:

Brass bar 2 = 36·000084 from comparison with Shuckburgh's scale, 0-36 in.
36·000280 " " " " 10-46 in.
36·000303 from comparison with the Ordnance yard, 1A.
36·000275 " " " " " 2A.
36·000229 from Capt. Kater's Royal Society yard.

Mean = 36·000234

Respecting this mean Mr. Sheepshanks wrote: "This should be pretty near the truth; but I prefer 36·00025, if in such a matter such a difference be worth notice. I propose, therefore, in constructing the new standard to assume that—

Brass bar 2 = 36·00025 inches of lost Imperial standard at 62° Fah."

And upon that basis the standard now in use was constructed.[1]

Turning now to the French standards of length, it is known that the ancient toise de maçons of Paris was probably the toise of Charlemagne (A. D. 742 to 814), or at least of some Emperor Charles, and that its étalon was situated in the court yard of the old Châtelet, on the outside of one of the pillars of the building. It still existed in 1714, but entirely falsified by the bending of the upper part of the pillar. In 1668 the ancient toise of the masons was reformed by shortening it five lines; but whether this reformation was an arbitrary change, or merely a change to remedy the effects of long use and restore the étalon to conformity with some more carefully preserved standard, is not quite clear.[1] These old *étalons* were iron bars having their two ends turned up at right angles so as to form *talons*, and the standardizing of end measures was effected by fitting them between the *talons*. Being placed on the outside of some public building, they were exposed to wear from constant use, to rust, and even to intentional injury by malicious persons. Under such conditions every étalon would, sooner or later, become too long and require shortening.

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[1] 41, p. 664.

Respecting the ancient toise of the masons there are two contradictory stories. On December 1, 1714, La Hire showed to the French Academy what he characterized as "a very ancient instrument of mathematics, which has been made by one of our most accomplished workmen with very great care, where the foot is marked, and which has served to re-establish the toise of the Châtelet, as I have been informed by our old mathematicians."[2] Forty-four years later, on July 29, 1758, La Condamine stated to the Academy that "We know only by tradition that to adjust the length of the new standard, the width of the arcade or interior gate of the grand pavilion, which served as an entrance to the old Louvre, on the side of the rue Fromenteau was used. This opening, according to the plan, should have been twelve feet wide. Half of it was taken to fix the length of the new toise, which thus became five lines shorter than the old one."[3] Of these two contradictory statements that of La Hire seems altogether most trustworthy, and the ordinary rules of evidence indicate that it should be accepted to the exclusion of the other.

In 1668 the étalon of the new toise, since known as the toise-étalon du Châtelet, was fixed against the wall at the foot of the staircase of the grand Châtelet de Paris—by whom or at what season of the year is not known. Strange as it now seems, this standard—very roughly made, exposed in a public place for use or abuse by everybody, liable to rust, and certain to be falsified by constant wear—was actually used for adjusting the toise of Picard, that of Cassini, the toise of Peru and of the North, that of La Caille, that of Mairan—in short, all the toises employed by the French in their geodetic operations during the seventeenth and eighteenth centuries. The lack of any other recognized standard made the use of this one imperative, but the French academicians were well aware of its defects and took precautions to guard against them.

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[1] 1, p. 536 and 2, p. 395.

[2] 2, p. 395.

[3] 14, p. 484.

The first toise copied from the étalon of the Châtelet for scientific purposes was that used by Picard in his measurement of a degree of the meridian between Paris and Amiens.[1] It was made about the year 1668, and would doubtless have become the scientific standard of France had it not unfortunately disappeared before the degree measurements of the eighteenth century were begun. The second toise copied from the étalon of the Châtelet for scientific purposes was that used by Messrs. Godin, Bouguer, and La Condamine for measuring the base of their arc of the meridian in Peru. This toise, since known as the toise du Pérou, was made by the artist Langlois under the immediate direction of Godin in 1735, and is still preserved at the Paris Observatory.[2] It is a rectangular bar of polished wrought iron, having a breadth of 1·58 English inches and a thickness of 0·30 of an inch. All the other toises used by the Academy in the eighteenth century were compared with it, and, ultimately, it was made the legal standard of France by an order of Louis XV, dated May 16, 1766. As the toise of Peru is the oldest authentic copy of the toise of the Châtelet, the effect of this order was simply to perpetuate the earliest known state of that ancient standard.

The metric system originated from a motion made by Talleyrand in the National Assembly of France, in 1790, referring the question of the formation of an improved system of weights and measures, based upon a natural constant, to the French Academy of Sciences; and the preliminary work was entrusted to five of the most eminent members of that Academy—namely, Lagrange, Laplace, Borda, Monge, and Condorcet. On March 19, 1791, these gentlemen, together with Lalande, presented to the Academy a report containing the complete scheme of the metric system. In pursuance of the recommendations in that report, the law of March 26, 1791, was enacted for the construction of the new system, and the Academy of Sciences was charged with the direction of the necessary operations. Those requisite for the construction of a standard of length were:

1. The determination of the difference of latitude between Dunkirk and Barcelona.

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[1] 5, Art. 4, p. 15.

[2] 14, p. 487 and 46, p. C.2.

2. The remeasurement of the ancient bases which had served for the measurement of a degree at the latitude of Paris, and for making the map of France.

3. The verification by new observations of the series of triangles employed for measuring the meridian, and the prolongation of them as far as Barcelona.

This work was entrusted to Méchain and Delambre, who carried it on during the seven years from 1791 to 1798, notwithstanding many great difficulties and dangers. The unit of length adopted in their operations was the toise of Peru, and from the arc of 9° 40′ 45″ actually measured, they inferred the length of an arc of the meridian extending from the equator to the pole to be 5,130,740 toises. As the meter was to be one ten millionth of that distance, its length was made 0·5130740 of a toise, or, in the language of the committee, 443·296 lines of the toise of Peru at a temperature of 13° Reaumur (16¼° C. or 61¼° F.).[1]

Before attempting to estimate how accurately the standards we have been considering were intercompared it will be well to describe briefly the methods by which the comparisons were effected. In 1742 Graham used the only instruments then known for the purpose—namely, very exact beam compasses of various kinds, one having parallel jaws for taking the lengths of the standard rods, another with rounded ends for taking the lengths of the hollow beds, and still another having fine points in the usual manner. The jaws, or points, of all these instruments were movable by micrometer screws having heads divided to show the eight hundredth part of an inch directly, and the tenth of that quantity by estimation; but Mr. Graham did not consider that the measurements could be depended upon to a greater accuracy than one 1600th of an inch.[2]

Troughton is generally regarded as the author of the application of micrometer microscopes to the comparison of standards of length, but the earliest record of their use for that purpose is by Sir George Shuckburgh in his work for the improvement of the standards of weight and measure in 1796–8.[3] Since then their use has been general; first, because they are more accurate than beam compasses, and, second, because they avoid the injury to standard scales which necessarily results from placing the points of beam compasses upon their graduations. As the objective of the microscope forms a magnified image of the standard, upon which the micrometer wires are set by the aid of the eye piece, it is evident that in order to reduce the effect of imperfections in the micrometer, the objective should have the largest practicable magnifying power. To show the progress in that direction the optical constants of the microscopes, by means of which some of the most important standards have been compared, are given in the accompanying table.

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[1] 19, pp. 432, 438 and 642. [2] 7, pp. 545–6. [3] 18, p. 137.

Date.	Observer.	Power of microscope.	Magnifying power of objective.	Equivalent focus of eye-piece.	Value of one revolution of micrometer screw.
				Inches.	*Inches.*
1797	Sir Geo. Shuckburgh	14	1.7	1.50	0·01000
1817	Capt. Henry Kater	18	(2.3)	--------	·00428
1834	Francis Baily	27	(2.0)	¾	·00500
1834	Lieut. Murphy, R. E.	------	(2.0)	--------	·00500
1850	R. Sheepshanks	------	(2.8)	--------	·00358
1864	Gen. A. R. Clarke, R. E.	60	4.	0.67	·00287
1880	Prof. W. A. Rogers, 1 in. obj.	------	(12.7)	--------	·00079
	" " ½ in. obj.	------	(28.6)	--------	·00035
	" " ¼ in. obj.	------	(52.7)	--------	·00019
1883	International Bureau	90	7.5	0.83	0·00394

NOTE.—The magnifying power of Sir Geo. Shuckburgh's microscope seems to be referred to a distance of twelve inches for distinct vision. The powers inclosed in parentheses are estimated upon the assumption that the respective micrometer screws had one hundred threads per inch.

In the memoirs of the French Academy nothing is said respecting the method adopted by the Academicians for comparing their various toises; but in his astronomy, Lalande states that the comparisons were effected partly by beam compasses, and partly by superposing the toises upon each other and examining their ends, both by touch and with magnifying glasses; they being all end standards.[1] For the definitive adjustment of the length of their meters, which were also end standards, the French Metric Commission used a lever comparator by Lenoir.

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[1] 16, p. 8.

In 1742 Graham used beam compasses, which he considered trustworthy to 0·00062 of an inch, in comparing standards of length; but at that time the French Academicians made their comparisons of toises only to one twentieth, or one thirtieth of a line, say 0·00300 of an inch, and it was not until 1758 that La Condamine declared they should be compared to 0·01 of a line, or 0·00089 of an English inch "if our senses aided by the most perfect instruments can attain to that."[1] Half a century later, ten times that accuracy was attained by the lever comparator of Lenoir, which was regarded as trustworthy to 0·000077 of an inch.[2]

The heads of micrometer microscopes are usually divided into one hundred equal parts, and if we regard one of these parts as the least reading of a microscope, then in 1797, Sir George Shuckburgh's microscopes read to one ten thousandth of an inch; and the least reading of microscopes made since that date has varied from one twenty thousandth to one thirty-five thousandth of an inch. A few investigators, among whom may be mentioned Professor W. A. Rogers, of Colby University, have made the least reading of their microscopes as small as one 90,000 of an inch, but it is doubtful if there is any advantage in so doing. At the present day the errors committed in comparing standards arise, not from lack of power in the microscopes, but from the difficulty of determining sufficiently exactly the temperature of the standard bars, and the effect of flexure upon the position of their graduations. In order to ascertain the length of a three foot standard with an error not exceeding 0·000020 of an inch, its temperature must be known to 0·06° F. if it is of brass, or to 0·09° F. if it is of iron. To get thermometers that will indicate their own temperature to that degree of accuracy is by no means easy, but to determine the temperature of a bar from their readings is far more difficult. Again, we imagine the length of our standards to follow their temperature rigorously, but what proof is there that such is the case? If we determine the freezing point of an old thermometer, then raise it to the temperature of boiling water, and immediately thereafter again determine its freezing point, we invariably find that the freezing point has fallen a little; and we explain this by saying that the glass has taken a set, from which it requires time to recover. Is it not probable that an effect similar in kind, although less in degree, occurs in all solids when their temparature is varying? When we look at the highly polished terminals of an end standard, we are apt to regard them as mathematical surfaces, separated by an interval which is perfectly definite, and which could be measured with infinite precision if we only had the necessary instrumental appliances; but is that a correct view? The atomic theory answers emphatically, No. According to it, all matter consists of atoms, or molecules, of a perfectly definite size, and with definite intervals between them; but even if that is denied, the evidence is now overwhelming that matter is not homogeneous, but possesses a grain of some kind, regularly repeated at intervals which cannot be greater than one 2,000,000th nor less than one 400,000,000th of an inch. Accordingly, we must picture our standard bar as a conglomeration of grains of some kind or other, having magnitudes of the order specified, and all in ceaseless motion, the amplitude of which depends upon the temperature of the bar. To our mental vision the polished terminals are therefore like the surface of a pot of boiling water, and we recognize that there must be a limit to the accuracy with which the interval between them can be measured. As a basis for estimating how near this limit we have approached, it will suffice to say that for fifty years past it has been customary to state comparisons of standards of length to one 1,000,000th of an inch. Nevertheless, most authorities agree that although one 100,000th of an inch can be distinguished in the comparators, one 25,000th of an inch is about the limit of accuracy attainable in comparing standards. Possibly such a limit may be reached under the most favorable circumstances, but in the case of the yard and the meter, which are standard at different temperatures, the following values of the meter by observers of the highest repute render it doubtful if any thing like that accuracy has yet been attained.

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[1] 14, p. 483.

[2] Base du Système Métrique. T. 3, pp. 447–462.

1818.	Capt. Henry Kater	39·37079	inches.
1866.	Gen. A. R. Clarke	39·37043	"
1883.	Prof. Wm. A. Rogers	39·37027	"
1885.	Gen. C. B. Comstock	39·36985	"

The earliest standard of English weight of which we have any very definite knowledge is the mint pound of the Tower of London. It weighed 5,400 troy grains, and the coinage was regulated by it up to the year 1527, when it was abolished in favor of the troy pound of 5,760 grains. Contemporaneously with the tower pound there was also the merchant's pound, whose exact weight is now involved in so much doubt that it is impossible to decide whether it consisted of 6,750 or of 7,200 grains. The tower pound and the troy pound were used for weighing only gold, silver, and drugs, while all other commodities were weighed by the merchant's pound until the thirteenth or fourteenth century, and after that by the avoirdupois pound. It is not certainly known when the troy and avoirdupois pounds were introduced into England, and there is no evidence of any relation between them when they first became standards. The present avoirdupois pound can be clearly proved to be of similar weight to the standard avoirdupois pound of Edward III (A. D. 1327–1377), and there is good reason for believing that no substantial change has occurred either in its weight or in that of the troy pound since their respective establishment as standards in England.

The oldest standard weights now existing in the English archives date from the reign of Queen Elizabeth, and consist of a set of bell-shaped avoirdupois weights of 56, 28, and 14 pounds, made in 1582 and 7, 4, 2, and 1 pounds made in 1588; a set of flat circular avoirdupois weights of 8, 4, 2, and 1 pounds, and 8, 4, 2, 1, ½, ¼, ⅛, and $\frac{1}{16}$ ounces, made in 1588; and a set of cup-shaped troy weights, fitting one within the other, of 256, 128, 64, 32, 16, 8, 4, 2, 1, ½, ¼, ⅛ (hollow), and ⅛ (solid) ounces, also made in 1588.[1] All these standards were constructed by order of Queen Elizabeth, under the direction of a jury composed of eighteen merchants and eleven goldsmiths of London; the avoirdupois weights being adjusted according to an ancient standard of 56 pounds, remaining in the Exchequer from the time of Edward III; and the troy weights being adjusted according to the ancient standard in Goldsmiths' Hall.[2]

In view of the fact that the weight mentioned in all the old acts of Parliament, from the time of Edward I (A. D. 1274–1307) is universally admitted to be troy weight, the Parliamentary Committee of 1758, appointed to inquire into the original standards of weights and measures in England, recommended that the troy pound should be made the unit or standard by which the avoirdupois and other weights should be regulated; and by their order three several troy pounds of soft gun-metal were very carefully adjusted under the direction of Mr. Joseph Harris, who was then assay master of the Mint. To ascertain the proper mass for these pounds the committee caused Messrs. Harris and Gregory, of the Mint, to perform the following operations in their presence:[1]

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[1] 11, p. 430.

[2] 11, pp. 435 and 443–448.

First.—In the before-mentioned set of troy weights, made in 1588, which were then the Exchequer standard, each weight, from that of 4 ounces up to that of 256 ounces, was compared successively with the sum of all the smaller weights; and by a process for which no valid reason can be assigned,[2] it was concluded from these weighings that the troy pound composed of the 8 and 4 ounce weights was 1½ grains too light.

Second.—The aforesaid 8 and 4 ounce weights of the Exchequer were compared with five other authoritative troy pounds, four of which belonged to the Mint and one to Mr. Freeman, who, like his father before him, was scale maker to the mint, and from the mean of these weighings it appeared that the sum of the Exchequer 8 and 4 ounce weights was one grain too light.

The Committee adopted the mean between the latter result and that which they had deduced from the Exchequer weights alone,[2] and accordingly Mr. Harris made each of his three troy pounds 1¼ grains heavier than the sum of the Exchequer 8 and 4 ounce weights; but sixty-six years were destined to elapse before Parliament took action respecting them.

The Commissioners appointed in 1818 to establish a more uniform system of weights and measures, repeated the recommendations of the committee of 1758,[3] and as the avoirdupois pound which had long been used, although not legalized by any act of the legislature, was very nearly 7,000 troy grains, they recommended that 7,000 such troy grains be declared to constitute a pound avoirdupois.[4] These recommendations were embodied in the act of Parliament of June 17, 1824, and thus one of the troy pounds made in 1758 became the Imperial standard. That standard, like Bird's standard yard, was deposited in the Houses of Parliament and was burned up with them in October, 1834.

The present English standard pound was made in 1844–46 by Prof. W. H. Miller, who was one of the members of the Commission appointed in 1843 to superintend the construction of the new parliamentary standards of length and weight destined to replace those destroyed in 1834. A number of weights had been very accurately compared with the lost standard; namely, in 1824 or 1825, by Capt. Kater, five troy pounds of gun-metal, destined respectively for the use of the Exchequer, the Royal Mint, and the cities of London, Edinburgh, and Dublin; and in 1829, by Capt. v. Nehus, two troy pounds of brass and one of platinum, all in the custody of Prof. Schumacher, and a platinum troy pound belonging to the Royal Society. The first step for recovering the mass of the lost standard was manifestly to compare these weights among themselves, and upon so doing it was found that for the brass and gun-metal weights the discrepancies between the weighings made in 1824 and 1844 amounted to 0·0226[1] of a grain, while for the two platinum weights the discrepancies between the weighings made in 1829 and 1845 was only 0·00019[2] of a grain. With a single exception, all the *new* brass or gun-metal weights had become heavier since their first comparison with the lost standard, the change being probably due to oxydation of their surfaces, and on that account the new standard was made to depend solely upon the two platinum weights. For convenience of reference these weights were designated respectively Sp (Schumacher's platinum), and RS (Royal Society). A provisional platinum troy pound, T, intermediate in mass between Sp and RS was next prepared, and from 286 comparisons made in January, February, July, and August, 1845, it was found that in a vacuum[3]

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[1] 11, p. 437. [2] See Note B, below. [3] See 23, 24, and 25. [4] 28, pp. 4–5.

$$T = Sp + 0{\cdot}00105 \text{ grain},$$

while from 122 comparisons made in January, July, and August, 1845,

$$T = RS - 0{\cdot}00429 \text{ grain}.$$

By combining these values with the results of the weighings made in 1824–29, namely,

$$Sp = U - 0{\cdot}52956 \text{ grain},$$
$$RS = U - 0{\cdot}52441 \text{ grain},$$

where U designates the lost standard—the comparisons with Sp gave

$$T = U - 0{\cdot}52851 \text{ grain},$$

while those with RS gave

$$T = U - 0{\cdot}52870 \text{ grain}.$$

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[1] 40, p. 772. [2] 40, p. 941. [3] 40, pp. 819–20.

To the first of these expressions double weight was assigned, because the comparisons of T and U with Sp were about twice as numerous as those with RS. The resulting mean was therefore

T = U — 0·52857 grains = 5759·47143 grains,

and from that value of T the new standard avoirdupois pound of 7000 grains was constructed.

From some time in the fifteenth century until the adoption of the metric system in August, 1793, the system of weights employed in France was the *poids de marc*, having for its ultimate standard the *pile de Charlemagne*, which was then kept in the Mint, and is now deposited in the Conservatoire des Arts et Métiers. The table of this weight was

72 grains = 1 gros = 72 grains.
8 gros = 1 once = 576 "
8 onces = 1 marc = 4608 "
2 marcs = 1 livre = 9216 "

The origin of the *pile de Charlemagne* is not certainly known, but it is thought to have been made by direction of King John (A. D. 1350–1364). It consists of a set of brass cup-weights, fitting one within the other, and the whole weighing fifty marcs. The nominal and actual weights of the several pieces are as follows:[1]

	Marcs.		*Grains.*
Boîte de 20 marcs .	20	+	1·4
Pièce de 14 " .	14	+	4·5
de 8 " .	8	—	0·4
de 4 " .	4	—	2·1
de 2 " .	2	—	1·0
de 1 " .	1	—	0·7
Marc divisé	1	—	1·7
	50	±	0·0

In determining the relation of the *poids de marc* to the metric weights, the committee for the construction of the kilogram regarded the entire *pile de Charlemagne* as a standard of fifty marcs, and considered the individual pieces as subject to the corrections stated. On that basis they found

1 kilogram = 18827·15 French grains[2]

and as a kilogram is equal to 15432·34874[3] English troy grains, we have

1 livre, poids de marc = 7554·22 troy grains.
= 489·506 grams.

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[1] 17, pp. 270–71. [2] Base du Système Métrique. T. 3, p. 638. [3] 40, p. 893.

The metric standard of weight, called a kilogram, was constructed under the direction of the French Academy of Sciences simultaneously with the meter; the work being done principally by Lefèvre-Gineau and Borda. It was intended that the kilogram should have the same mass as a cubic decimeter of pure water at maximum density, and the experimental determination of that mass was made by finding the difference of weight in air and in water of a hollow brass cylinder whose exterior dimensions at a temperature of 17·6° C. were, height = 2·437672 decimeters, diameter = 2·428368 decimeters, volume = 11·2900054 cubic decimeters. The difference of weight in question was first measured in terms of certain brass weights, by the aid of which the platinum kilogram of the archives was subsequently constructed, special care being taken to apply the corrections necessary to reduce all the weighings to what they would have been if made in a vacuum.[1]

The best results hitherto obtained for the weight of a cubic decimeter of water, expressed in terms of the kilogram of the archives, are as follows:[2]

Date.	Country.	Observer.	Weight of a cubic decimeter of water at 4° C.
			Grams.
1795	France	Lefèvre-Gineau	1000·000
1797 1821	England	Shuckburgh and Kater	1000·480
1825	Sweden	Berzelius, Svanberg, and Akermann	1000·296
1830	Austria	Stampfer	999·653
1841	Russia	Kupffer	999·989
		Mean	1000·084

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[1] Base du Système Métrique, T. 3, pp. 574–5.

[2] This table has been deduced from the data given by Prof. Miller in 40, p. 760.

These results show the extreme difficulty of determining the exact mass of a given volume of water. The discordance between the different observers amounts to more than one part in a thousand, while good weighings are exact to one part in eight or ten millions. Without doubt two weights can be compared at least a thousand times more accurately than either of them can be reproduced by weighing a specified volume of water, and for that reason the kilogram, like the English pound, can now be regarded only as an arbitrary standard of which copies must be taken by direct comparison. As already stated, the kilogram is equivalent to 15432·34874 English troy grains, or about two pounds three ounces avoirdupois.

In consequence of the circumstance that the mass of a body is not affected either by temperature or flexure, weighing is an easier process than measuring; but in order to obtain precise results many precautions are necessary. Imagine a balance with a block of wood tied to its right-hand pan and accurately counterpoised by lead weights in its left-hand pan. If with things so arranged the balance were immersed in water the equilibrium would be instantly destroyed and to restore it all the weights would have to be removed from the left-hand pan, and some of them would have to be placed in the right-hand pan to overcome the buoyancy of the wood. The atmosphere behaves precisely as the water does, and although its effect is minute enough to be neglected in ordinary business affairs, it must be taken into account when scientific accuracy is desired. To that end the weighing must either be made in a vacuum, or the difference of the buoyant effect of the air upon the substances in the two pans must be computed and allowed for. As very few vacuum balances exist, the latter method is usually employed. The data necessary for the computation are the latitude of the place where the weighing is made and its altitude above the sea level; the weights, specific gravities, and coefficients of expansion of each of the substances in the two pans; the temperature of the air, its barometric pressure, and the pressure, both of the aqueous vapor, and of the carbonic anhydride, contained in it.

Judging from the adjustment of the *pile de Charlemagne*, and the Exchequer troy weights of Queen Elizabeth, the accuracy attained in weighing gold and silver at the mints during the fourteenth, fifteenth, and sixteenth centuries must have been about one part in ten thousand. The balance which Mr. Harris of the London mint used in 1743 indicated one-eighth of a grain on a troy pound, or about one part in 50,000; while according to Sir George Shuckburgh the balance used by Messrs. Harris and Bird in making their observations upon the Exchequer weights, apparently in 1758 or 1759, turned with one 230,000th part of its load.[1] In 1798 Sir George Shuckburgh had a balance sensitive enough to indicate 0·01 of a grain when loaded with 16,000 grains, or about one part in 1,600,000. The balance used by Fortin in 1799, in adjusting the kilogram of the archives, was not quite so delicate, its sensitiveness being only the 1,000,000th part of its load; but in 1844, for the adjustment of the present English standard pound, Professor Miller employed a balance whose index moved about 0·01 of an inch for a change of 0·002 of a grain in a load of 7,000 grains.[2] He read the index with a microscope, and found the probable error of a single comparison of two avoirdupois pounds to be one 12,000,000th of either, or about 0·00058 of a grain. At the present time it is claimed that two avoirdupois pounds can be compared with an error not exceeding 0·0002 of a grain; and two kilograms with an error not exceeding 0·02 of a milligram.

The mean solar day is the natural unit of time for the human race, and it is universally adopted among all civilized nations. Our ultimate standard of time is therefore the rotation of the earth upon its axis, and from that rotation we determine the errors of our clocks and watches by astronomical observations. For many purposes it suffices to make these observations upon the sun, but when the utmost precision is desired it is better to make them on the stars. Until the close of the seventeenth century quadrants were employed for that purpose, and so late as 1680 Flamsteed, the first English astronomer royal, thought himself fortunate when he succeeded in constructing one which enabled him to be sure of his observed times within three seconds.[3] About 1690 Roemer invented the transit instrument, which soon superseded the quadrant, and still remains the best appliance for determining time Most of his observations were destroyed by a fire in 1728, but the few which have come down to us show that as early as 1706 he determined time with an accuracy which has not yet been very greatly sur-passed. Probably the corrections found in the least square adjustment of extensive systems of longitude determinations afford the best criterion for estimating the accuracy of first-class modern time observations, and from them it appears that the error of such observations may rise as high as ± 0·05 of a second.

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[1] 18, p. 148. [2] 40, pp. 762 and 943.

[3] Account of the Rev. John Flamsteed. By Francis Baily. pp. 45–6. (London, 1835. 4to.)

During the intervals between successive observations of the heavenly bodies we necessarily depend upon clocks and chronometers for our knowledge of the time, and very erroneous ideas are frequently entertained respecting the accuracy of their running. The subject is one upon which it is difficult to obtain exact information, but there are few time-pieces which will run for a week without varying more than three-quarters of a second from their predicted error. As the number of seconds in a week is 604,800, this amounts to saying that the best time-pieces can be trusted to measure a week within one part in 756,000. Nevertheless, clocks and chronometers are but adjuncts to our chief time-piece, which is the earth itself, and upon the constancy of its rotation depends the preservation of our present unit of time. Early in this century Laplace and Poisson were believed to have proved that the length of the siderial day had not changed by so much as the one hundredth part of a second during the last 2,500 years, but later investigations show that they were mistaken, and, so far as we can now see, the friction produced by the tides in the ocean must be steadily reducing the velocity with which the earth rotates about its axis. The change is too slow to become sensible within the lifetime of a human being, but its ultimate consequences will be most momentous.

Ages ago it was remarked that all things run in cycles, and there is enough truth in the saying to make it as applicable now as on the day it was uttered. The Babylonian or Chaldean system of weights and measures seems to be the original from which the Egyptian system was derived, and is probably the most ancient of which we have any knowledge. Its unit of length was the cubit, of which there were two varieties, the natural and the royal. The foot was two-thirds of the natural cubit. Respecting the earliest Chaldean and Egyptian system of weights no very satisfactory information exists, but the best authorities agree that the weight of water contained in the measure of a cubic foot constituted the talent, or larger unit of weight, and that the sixtieth or fiftieth parts of the talent constituted, respectively, the Chaldean and Egyptian values of the mina, or lesser unit of commercial weight. Doubtless these weights varied considerably at different times and places, just as the modern pound has varied, but the relations stated are believed to have been the original ones. The ancient Chaldeans used not only the decimal system of notation, which is evidently the primitive one, but also a duodecimal system, as shown by the division of the year into twelve months, the equinoctial day and night each into twelve hours, the zodiac into twelve signs, etc., and a sexagesimal system by which the hour was divided into sixty minutes, the signs of the zodiac into thirty parts or degrees, and the circle into 360 degrees, with further sexagesimal subdivisions. The duodecimal and sexagesimal systems seem to have originated with the Chaldean astronomers, who, for some reason which is not now evident, preferred them to the decimal system, and by the weight of their scientific authority impressed them upon their system of weights and measures. Now observe how closely the scientific thought of to-day repeats the scientific thought of four thousand years ago. These old Chaldeans took from the human body what they regarded as a suitable unit of length, and for their unit of mass they adopted a cube of water bearing simple relations to their unit of length. Four thousand years later, when these simple relations had been forgotten and impaired, some of the most eminent scientists of the last century again undertook the task of constructing a system of weights and measures. With them the duodecimal and sexagesimal systems were out of favor, while the decimal system was highly fashionable, and for that reason they subdivided their units decimally instead of duodecimally, sexagesimally, or by powers of two; but they reverted to the old Chaldean device for obtaining simple relations between their units of length and mass, and to that fact alone the French metric system owes its survival. Every one now knows that the meter is not the ten millionth part of a quadrant of the earth's meridian, and in mathematical physics, where the numbers are all so complicated that they can only be dealt with by the aid of logarithms, and the constant π, an utterly irrational quantity, crops up in almost every integral, mere decimal subdivision of the units counts for very little. But in some departments of science, as, for example, chemistry, a simple relation between the unit of length (which determines volume), the unit of mass, and the unit of specific gravity, is of prime importance; and wherever that is the case the metric system will be used. To engineers such relations are of small moment, and consequently among English-speaking engineers the metric system is making no progress, while, on the other hand, the chemists have eagerly adopted it. As the English yard and pound are the direct descendants of the Chaldean-Babylonian natural cubit and mina, it is not surprising that the yard should be only 0·48 of an inch shorter than the double cubit, and the avoirdupois pound only 665 grains lighter than the Babylonian commercial mina; but, considering the origin of the metric system, it is rather curious that the meter is only 1·97 inches shorter than the Chaldean double royal cubit, and the kilogram only 102 grains heavier than the Babylonian royal mina. Thus, without much exaggeration, we may regard the present English and French fundamental units of length and mass as representing respectively the commercial and royal units of length and mass of the Chaldeans of four thousands years ago.

Science tells us that the energy of the solar system is being slowly dissipated in the form of radiant heat; that ultimately the sun will grow dim; life will die out on the planets; one by one they will tumble into the expiring sun; and at last darkness and the bitter cold of the absolute zero will reign over all. In that far-distant future imagine some wandering human spirit to have penetrated to a part of space immeasurably beyond the range of our most powerful telescopes, and there, upon an orb where the mechanical arts flourish as they do here, let him be asked to reproduce the standards of length, mass, and time with which we are now familiar. In the presence of such a demand the science of the seventeenth and eighteenth centuries would be powerless. The spin of the earth which measures our days and nights would be irretrievably gone; our yards, our meters, our pounds, our kilograms would have tumbled with the earth into the ruins of the sun, and become part of the debris of the solar system. Could they be recovered from the dead past and live again? The science of all previous ages mournfully answers, No; but with the science of the nineteenth century it is otherwise. The spectroscope has taught us that throughout the visible universe the constitution of matter is the same. Everywhere the rythmic motions of the atoms are absolutely identical, and to them, and the light which they emit, our wandering spirit would turn for the recovery of the long-lost standards. By means of a diffraction grating and an accurate goniometer he could recover the yard from the wave length of sodium light with an error not exceeding one or two thousandths of an inch. Water is everywhere, and with his newly recovered yard he could measure a cubic foot of it, and thus recover the standard of mass which we call a pound. The recovery of our standard of time would be more difficult; but even that could be accomplished with an error not exceeding half a minute in a day. One way would be to perform Michelson's modification of Foucault's experiment for determining the velocity of light. Another way would be to make a Siemen's mercury unit of electrical resistance, and then, either by the British Association method or by Lord Rayleigh's modification of Lorenz's method, find the velocity which measures its resistance in absolute units. Still another way would be to find the ratio of the electro-static and electro-magnetic units of electricity. Thus all the units now used in transacting the world's business could be made to reappear, if not with scientific, at least with commercial accuracy, on the other side of an abyss of time and space before which the human mind shrinks back in dismay. The science of the eighteenth century sought to render itself immortal by basing its standard units upon the solid earth, but the science of the nineteenth century soars far beyond the solar system and connects its units with the ultimate atoms which constitute the universe itself.

NOTE A.

The appended table exhibits the principal comparisons hitherto made of the more important early English standards of length. The significations of the reference numbers, and the authorities for the descriptions of the standards, are as follows:

No. 1. Standard yard of Henry VII (1490); an end measure formed of an octagonal brass rod half an inch in diameter.

No. 2. Standard yard of Queen Elizabeth (1588); an end measure formed of a brass rod six-tenths of an inch square.

No. 3. Matrix to Queen Elizabeth's standard yard (1588); of brass, 1½ inches wide, 1 inch thick, and 49 inches long.

No. 4. Standard ell of Queen Elizabeth (1588); an end measure of brass, six-tenths of an inch square.

No. 5. Standard yard of the Clock-makers' Company (1671); a matrix, formed by two pins in an octagonal brass rod half an inch in diameter.

No. 6. Standard yard at the Tower; a line measure, marked on a brass bar seven-tenths of an inch square and 41 inches long.

No. 7. Graham's Royal Society scale (1742); a line measure, on a brass bar half an inch wide, one-quarter of an inch thick, and 42 inches long. Line marked E. Mem. Roy. Ast. Soc., Vol. 9, p. 82.

No. 8. Ditto. Line marked Exch.

No. 9. Ditto. Paris half toise; marked F.

Numbers 1 to 9 are described in the Philosophical Transactions, 1743, pp. 547–550.

No. 10. Bird's standard yard of 1758; a line measure, on a brass bar 1·01 inches square, and 39·06 inches long. Mem. Roy. Ast. Soc., Vol. 9, p. 80.

No. 11. Bird's standard yard of 1760; a line measure, on a brass bar 1·05 inches square, and 39·73 inches long. Mem. Roy. Ast. Soc., Vol. 9, pp. 80–82.

No. 12. General Roy's scale; a line measure, upon a brass bar 0·55 of an inch broad, about 0·22 of an inch thick, and 42·8 inches long; divided by Bird. Phil. Trans., 1785, p. 401, and Measurement of Lough Foyle Base, p. 73.

No. 13. Ramsden's bar, used in the trigonometrical survey of Great Britain. Phil. Trans., 1821, p. 91; and Measurement of Lough Foyle Base, pp. 73–4.

No. 14. Sir Geo. Shuckburgh's scale (1796); a line measure, upon a brass bar 1·4 inches broad, 0·42 of an inch thick, and 67·7 inches long. Space compared, 0^{in} to 36^{in}. Phil. Trans., 1798, p. 133, and Mem. Roy. Ast. Soc., Vol. 9, pp. 84–5.

No. 15. Ditto. Space compared, 10^{in} to 46^{in}.

No. 16. Ordnance yard 1A (1827); a line measure, upon an iron bar 1·45 inches broad, 2·5 inches deep, and rather more than 3 feet long. Measurement of Lough Foyle Base, pp. 71, 82 and [28].

No. 17. Ordnance yard 2A (1827). Similar to 1A. Same authorities.

No. 18. Captain Kater's Royal Society yard (1831); a line measure, upon a brass plate 0·07 of an inch thick. Phil. Trans., 1831, p. 345.

No. 19. The Royal Astronomical Society's standard scale (1834); a line measure, upon a brass tube 1·12 inches exterior diameter, 0·74 of an inch interior diameter, and 63 inches long. The central yard was the space compared. Mem. Roy. Ast. Soc., Vol. 9, p. 69.

No. 20. "Col. Lambton's standard;" a line measure, upon a brass plate 0·92 of an inch broad, 0·21 of an inch thick, and 66½ inches long; strengthened by an edge bar of nearly the same breadth, but only 0·08 of an inch thick. Phil. Trans., 1821, p. 88, and Mem. Roy. Ast. Soc., Vol. 9, pp. 82–3.

The authorities for the comparisons given in the various columns of the table are as follows:

Column A.—Comparisons by Mr. George Graham. Phil. Trans., 1743, pp. 187, and 547–550.

Column B.—Comparisons by Sir Geo. Shuckburgh. Phil. Trans., 1798, pp. 167–181.

Column C.—Comparisons by Capt. Kater. Phil. Trans., 1818, p. 55, and 1821, p. 91.

Column D.—Comparisons by Capt. Kater. Phil. Trans., 1830, p. 377, and 1831, p. 347.

Column E.—Comparisons by Francis Baily, Esq. Mem. Roy. Ast. Soc., Vol. 9, p. 145.

Column F.—Comparisons by Francis Baily, Esq. Mem. Roy. Ast. Soc., Vol. 9, p. 120.

Column G.—Values adopted by R. Sheepshanks, Esq. Phil. Trans., 1857, p. 661.

The values used by Mr. Sheepshanks in 1848 to determine the length of the present Imperial standard yard were Nos. 14 D, 15 F, 16 and 17 G, and 18 D.

It will be observed that several different units are employed in the various columns of the table, and care must be taken to allow for that circumstance when comparing numbers not situated in the same column.

Comparisons of the Fundamental English Standards of Length.

Ref. No.	A.	B.	C.	D.	E.	F.	G.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1......	35·9929	35·966					
2......	36·0000	35·993					
3......	36·0102						
4......	45·0494	44.964					
5......	35·9790						
6......	36·0111						
7......	36·0075	36·0013	36·002007	....	36·001473		
8......	36·0000	35·9933	....	....	35·993684		
9......	38·355	38·3561					
10......	....	36·00023	36·000802				
11......	....	....	36.000659	36·000000	35·999624	36·000000	36.000000
12......	....	....	36·001537				
13......	....	....	36·003147				
14......	....	....	36·000642	36·00009	36·000185		
15......	....	36·0000	....	....	35·999921	36·000058	
16......	....	....	....	....	....	....	35·999716
17......	....	....	....	....	....	....	35·999892
18......	....	....	....	35·99938			
19......	....	....	....	....	36·000000		
20......	....	....	36·000000				

NOTE B.

By direction of the Parliamentary Committee of 1758, and in the presence both of that body and of Mr. Farley, deputy chamberlain, Messrs. Harris and Gregory of the London Mint compared the several standard troy weights of the Exchequer, with the following results:

4-oz. weight = All smaller weights — ¼ grain.
8-oz. " = " + ½ "
16-oz. " = " + ¼ "
32-oz. " = " + 2 grains.
64-oz. " = " + 3 "
128-oz. " = " + 14 "
256-oz. " = " — 21 "

The weighings which yielded these results were made at the London Mint; the instruments employed being "a very curious and exact pair of scales, belonging to Mr. Harris, and the scales used at the Mint for the weighing of gold." After recording the results in their report,[1] the Committee continued as follows:

> "Therefore beginning the difference from the sixteen-ounce weight, and carrying it on to the greatest troy weight in the Exchequer, the total difference will be eight grains and one-half."
>
> "The fourth part of which is two grains upon sixteen ounces, which is a grain and a half upon the twelve ounces or pound troy."
>
> "Then the eight and four ounces troy of the Exchequer were compared with the following weights:"
>
> "*First*, with the pound troy used at the Mint in weighing of gold, which was heavier than that at the Exchequer one grain."
>
> "*Secondly*, with the eight and four ounces at the Mint of the 6th of Queen *Anne*, 1707, which was heavier than that at the Exchequer half a grain."
>
> "The eight and four ounces of Queen *Elizabeth* 1588 at the Mint, was heavier than that at the Exchequer three quarters of a grain; another of the same year of Queen *Elizabeth* at the Mint, stampt with a tower, a thistle and crown, and EL and crown, was heavier than that at the Exchequer one grain."

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[1] 11, p. 487.

"Mr. *Freeman* produced a four and eight ounce of the 6th of Queen *Anne* 1707 by which he makes weights for sale, which was heavier than the same weights at the Exchequer one grain and three quarters: Therefore, upon an average of all these weights, the pound troy should be one grain heavier than the weights at the Exchequer, and that added to the grain and a half, which, upon the former experiments, the weights at the Exchequer are too light a medium taken from thence makes the proper increase of the Exchequer pound troy to be one grain and one quarter."

"And it is to be observed, that the pound troy weight at the Mint, which is now used for gold, and the eight and four ounces at the Mint, marked with a tower, and in the time of Queen *Elizabeth*, are both one grain heavier than the eight and four ounces of the Exchequer."

"And considering that the Exchequer weights have been used ever since the 30th of Queen *Elizabeth*, 1588, one hundred and seventy years to size other weights by, it is highly probable that the difference may have been occasioned by the frequent use of the standard."

"Your Committee endeavored to compare the troy weights with the original standard at *Goldsmith's Hall*, from whence it is said, in the aforesaid verdict of the 29th and 30th of *Elizabeth*, that the weights now at the Exchequer were made, and for that purpose sent to *Goldsmith's Hall* for the said weights; but were informed that no such were to be found there, the Goldsmith's having no weights older than those at the Exchequer;"

The Committee's statement respecting the way in which the correction of 1½ grains was deduced from the weighings of the Exchequer weights is very obscure, and the result is not justified by generally accepted principles. If we put x for the sum of all the weights smaller than 4 ounces, then the results of the weighings made by the Committee may be written in the form:

$$\begin{aligned}
\text{4-oz. divided} &= 1\,x \\
\text{4-oz. weight} &= 1\,x - \tfrac{1}{4}\text{ grain.} \\
\text{8-oz. weight} &= 2\,x + \tfrac{1}{4}\text{ grain.} \\
\text{16-oz. weight} &= 4\,x + \tfrac{1}{4}\text{ grain.} \\
\text{32-oz. weight} &= 8\,x + 2\tfrac{1}{4}\text{ grains.} \\
\text{64-oz. weight} &= 16\,x + 5\tfrac{1}{2}\text{ grains.} \\
\text{128-oz. weight} &= 32\,x + 22\text{ grains.} \\
\text{256-oz. weight} &= 64\,x + 9\text{ grains.}
\end{aligned} \tag{1}$$

Before proceeding further we must decide in what sense these weights are to be regarded as standards, and perhaps the most natural course will be to regard the entire set as a standard of 512 troy ounces. In that case the summation of the several columns gives

$$512 \text{ ounces} = 128\,x + 39 \text{ grains}$$

whence

$$x = 4 \text{ ounces} - 0{\cdot}3047 \text{ grain} \qquad (2)$$

and by substituting that value in the equations (1) we obtain the corrections to the several weights given in the second column of Table I.

TABLE I.—*Corrections to the Exchequer Standard Troy Weights of* 1588, *derived from the Weighings made by Messrs. Harris and Chisholm.*

Denomination of Weight.	Apparent correction in 1758.	Committee's correction in 1758.	Chisholm's correction in 1873.	Loss by wear in 115 years.
	Grains.	*Grains.*	*Grains.*	*Grains.*
4 ounces divided	— 0·30	— 0·42	— 1·69	— 1·27
4 ounces	·55	·67	0·68	0·01
8 ounces	·36	0·58	1 09	0·51
16 ounces	·97	1·42	3·84	2·42
32 ounces	— 0·19	1·08	3·82	2·74
64 ounces	+ 0·62	— 1·17	— 5·04	3·87
128 ounces	+ 12·25	+ 8·67	+ 4·28	4·39
256 ounces	— 10·50	— 17·67	— 53·58	— 35·91
Sums	± 0·00	— 14·34	— 65·46	— 51·12

From equations (1) and (2) we have

$$4 \text{ ounces} = 4\text{-oz. weight} + 0{\cdot}5547 \text{ grain.}$$
$$8 \text{ ounces} = 8\text{-oz. weight} + 0{\cdot}3594 \text{ grain.}$$

whence it follows that the sum of the eight and four ounce weights, which constituted the Exchequer standard troy pound, was too light by 0·9141 of a grain. As the mean correction obtained from the four weights belonging respectively to the Mint and to Mr. Freeman agrees closely with this result, the true correction to the Exchequer standard must have been very approximately one grain;

and in adopting one and one-quarter grains the Committee seem to have augmented the weight of the troy pound by about one-quarter of a grain. The corrections which result to the Exchequer troy weights upon the Committee's assumption that the sum of the eight and four ounce weights was one and one-quarter grains too light are given in the third column of Table I; while the fourth column contains the corrections found by Mr. Chisholm in 1873,[1] and the fifth column shows the loss of weight which occurred between 1758 and 1873. In view of the fact that these weights were constantly used for comparing local standards during a period of no less than 225 years, from 1588 to 1825, their excellent preservation is very remarkable.

In the report of the Committee of 1758 there is another set of comparisons of the Exchequer troy weights;[2] said comparisons having been made on April 14, 1758, in accordance with the directions of the Committee, by Mr. Freeman and Mr. Reed, expert scale makers, in the presence of Mr. Farley, deputy chamberlain. They are as follows:

⅛-oz. hollow = ⅛-oz. solid + ½ grain.
¼-oz. weight = All smaller weights — ½ grain.
½-oz. “ = “ — ½ “
1-oz. “ = “ — ½ “
2-oz. “ = “ — ½ “
4-oz. “ = “ ± 0 grains.
8-oz. “ = “ ± 0 “
16-oz. “ = “ ± 0 “
32-oz. “ = “ — 2 “
64-oz. “ = “ ± 0 “
128-oz. “ = “ + 15 “
256-oz. “ = “ — 24 “

In these equations the symbol ± 0 is used to indicate the relation which the Committee expressed by saying that the weights "very nearly agreed."

Regarding the entire set of weights as a standard of 512 ounces, and putting x for the mass of the ⅛-oz. solid weight, we have

⅛-oz. solid = $1x$.
⅛-oz. hollow = $1x + \frac{1}{2}$ grain.

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[1] 43, p. 21.

[2] 11, p. 435.

$$\begin{array}{rcl}
\tfrac{1}{4}\text{-oz. weight} & = & 2x. \\
\tfrac{1}{2}\text{-oz. }\ \text{"} & = & 4x. \\
1\text{-oz. }\ \text{"} & = & 8x. \\
2\text{-oz. }\ \text{"} & = & 16x. \\
4\text{-oz. }\ \text{"} & = & 32x + \tfrac{1}{2}\text{ grain.} \\
8\text{-oz. }\ \text{"} & = & 64x + 1\ \ \text{"} \\
16\text{-oz. }\ \text{"} & = & 128x + 2\text{ grains.} \\
32\text{-oz. }\ \text{"} & = & 256x + 2\ \ \text{"} \\
64\text{-oz. }\ \text{"} & = & 512x + 6\ \ \text{"} \\
128\text{-oz. }\ \text{"} & = & 1024x + 27\ \ \text{"} \\
256\text{-oz. }\ \text{"} & = & 2048x + 15\ \ \text{"}
\end{array} \tag{3}$$

Summing the various columns

$$512 \text{ ounces} = 4096x + 54 \text{ grains}$$

whence

$$x = \tfrac{1}{8} \text{ ounce} - 0{\cdot}01318 \text{ grains}, \tag{4}$$

and by substituting that value in the equations (3) we obtain the corrections given for the several weights in the second column of Table II. The third column contains the corrections which result upon the Committee's assumption that the sum of the eight and four ounce weights was one and one-quarter grains too light; and the fourth and fifth colums contain corrections given by Mr. Chisholm in his seventh annual report.[1] Mr. Chisholm does not explain how he obtained the corrections quoted in the fourth column of the table, but their close agreement with those in the third column renders it almost certain that they were computed from the comparisons made by Messrs. Freeman and Reed. As the Committee of 1758 used Mr. Harris' weighings *to the exclusion of those by Messrs. Freeman and Reed,* the adoption of the opposite course by Mr. Chisholm is perhaps explained by the circumstance that in his report on the Exchequer standards[2] *he has quoted the weighings by Messrs. Freeman and Reed and has attributed them to Mr. Harris.*

In addition to being less exact, the weighings by Mr. Freeman differ from those by Mr. Harris principally in the sign of the correction to the 32-ounce weight; the former stating that the 32-ounce weight was lighter than the sum of all the smaller weights, and the latter that it was heavier. To ascertain which was right we have only to compare the resulting systems of corrections with those found by Mr. Chisholm in 1873. Table I shows that according to Mr. Harris' weighings all the weights have grown lighter during the interval from 1758 to 1873, while Table II shows that according to Mr. Freeman's weighings some have grown lighter and others heavier, and that by quantities which cannot be attributed to accidental errors in the weighings. In view of these facts there cannot be a doubt that the Committee of 1758 was right in using only Mr. Harris' weighings, and it seems equally certain that the numbers in Table I should be adopted to the exclusion of those in Table II.

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[1] 43, p. 21.

[2] 48, p. 11.

TABLE II.—*Corrections to the Exchequer Standard Troy Weights of* 1588, *derived from the Weighings made by Messrs. Freeman and Chisholm.*

Denomination of Weight.	Apparent correction in 1758.	Committee's correction in 1758.	Corrections given by Mr. Chisholm	
			in 1758.	in 1873.
	Grains.	*Grains.*	*Grains.*	*Grains.*
⅛ ounce solid	— 0·01	— 0·03	0·0	— 0·06
⅛ ounce hollow	+ 0·49	+ 0·47	+ 0·5	+ 0·40
¼ ounce	— 0·03	— 0·06	·0	— 0·21
½ ounce	·05	·11	·0	·36
1 ounce	·11	·23	0·0	0·45
2 ounces	— 0·21	·46	— 1·0	1·01
4 ounces	+ 0·08	·42	0·5	0·68
8 ounces	·16	0·83	0·75	1·09
16 ounces	+ 0·31	1·68	1·75	3·84
32 ounces	— 1·38	5·36	5·5	3·82
64 ounces	— 0·75	8·70	— 9·0	— 5·04
128 ounces	+ 13·50	2·40	+ 3·0	+ 4·28
256 ounces	— 12·00	— 43·81	— 45·0	— 53·58
Sums	± 0·00	— 63·62	— 61·0	— 65·46

From comparisons of their troy pound with their avoirdupois pound, and with the two-marc weight sent to them by the French Academy in 1742, the Royal Society of London found[1]—

1. That the English avoirdupois pound weighed 7,004 troy grains;
2. That the French *livre*, consisting of two marcs, weighed 7,560 troy grains;

and for three-quarters of a century the latter value was universally accepted. Further, when the metric system came into being, the kilogram was declared to consist of 18,827·15 French grains, of which the livre contained 9216[2]; or, in other words, the kilogram was declared equal to 2·04288 livres; whence, *with the Royal Society's value of the livre*, the English equivalent of the kilogram was computed to be 15,444 troy grains.

During some experiments at the London Mint in March, 1820, it was found that the French livre belonging to that institution weighed only 7555 troy grains. This discovery led to an examination of the Royal Society's standards of 1742, which had been carefully preserved, and it was found that their livre agreed with that at the Mint, but their troy pound was nearly four grains lighter than the Imperial standard of 1758, and their avoirdupois pound weighed only 7000 troy grains instead of 7004.[3] Thus it was rendered almost certain that the accepted English equivalent of the kilogram was about ten grains too large, and to remove all possible doubt, a direct comparison of the English and French standards of weight was effected in 1821[4], through the co-operation of the respective governments, and then it was definitively ascertained that the weight of the kilogram is only 15,433 troy grains.

The facts respecting the Royal Society's standards of 1742 are as follows:

1. The weighings recorded in the Philosophical Transactions, 1743, pages 553 and 556, give

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[1] 6, p. 187. It is usual to designate 1742 as the date of the exchange of standards, but the remark of Cassini de Thury (4, p. 135) shows that the true date must have been prior to April, 1738. In his paper of November, 1742, Graham makes only the indefinite statement that the exchange was "proposed some time since."

[2] Base du Système Métrique, T. 3, p. 638.

[3] See 36, Vol. 1, p. 140, and 28, p. 19.

[4] 28, pp. 19-22.

R. S. troy lb. = Exch. (8 oz. + 4 oz.) — ½ grain. (5)

R. S. troy lb. = Mint (8 oz. + 4 oz.) — 2⅜ grains. (6)

whence

Exch. (8 oz. + 4 oz.) = Mint (8 oz. + 4 oz.) — 1⅞ grains. (7)

2. The weighings by Mr. Harris, for the Parliamentary Committee of 1758, give[1]

Exch. (8 oz. + 4 oz.) = Mint (8 oz. + 4 oz.) — ½ grain. (8)

whence, by (6),

R. S. troy lb. = Exch. (8 oz. + 4 oz.) — 1⅞ grains. (9)

In equations (6) and (8) the weights at the Mint were those of the sixth of Queen Anne, 1707.

3. In the Philosophical Transactions, 1742, page 187, it is stated that the Paris two-marc weight weighs 7560 troy grains. As the true weight of two marcs is 7554·22 grains, this implies that the Royal Society's troy pound was too light by 5·78 (5760 ÷ 7560) = 4·40 grains.

In the Philosophical Transactions, 1742, page 187, it is stated that the Royal Society's avoirdupois pound weighed 7004 troy grains, while the comparisons made in 1820 show that its weight was then only 7000 such grains. This implies that the Royal Society's troy pound was too light by 4 00 (5760 ÷ 7000) = 3·29 grains.

Finally, the comparisons of 1820 showed that the Royal Society's troy pound was "nearly four grains too light."

The mean of these three independent results shows that the Royal Society's troy pound was 3·9 grains lighter than the Imperial standard of 1758; whence

R. S. troy lb. + 3·9 grains = Standard of 1758 (10)

but

Standard of 1758 = Exch. (8 oz. + 4 oz.) + 1¼ grains (11)

and therefore

R. S. troy lb. = Exch. (8 oz. + 4 oz.) — 2⅝ grains. (12)

Considering the indefiniteness of the data respecting the weighings made in 1820, equations (9) and (12) agree fairly well, but equation (5) is very discordant, as are also equations (7) and (8). All the evidence seems to point to an error of about one and one half grains in equation (5); and if instead of (5) we write

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[1] 11, p. 487.

$$\text{R. S. Troy lb.} = \text{Exch. } (8 \text{ oz.} + 4 \text{ oz.}) - 2 \text{ grains} \qquad (5')$$

(7) will become

$$\text{Exch. } (8 \text{ oz.} + 4 \text{ oz.}) = \text{Mint } (8 \text{ oz.} + 4 \text{ oz.}) - \tfrac{3}{8} \text{ grain} \qquad (7')$$

and then all the equations will be reasonably accordant.

LIST OF THE PRINCIPAL AUTHORITIES CONSULTED IN THE PREPARATION OF THE FOREGOING ADDRESS.

NOTE.—The abbreviation "E. P. P." is used to designate English Parliamentary Papers. Some of these papers are of folio size and others of octavo size, but in the official sets they are all bound up indiscriminately in volumes of folio size, measuring 13 by 8½ inches.

Throughout the preceding pages authorities in this list are usually cited by number and page. For example, "27, p. 91" would indicate page 91 of Capt. Kater's account of his comparisons of various British standards of linear measure, contained in the Philosophical Transactions for 1821.

1.—PICARD; M. L'ABBÉ. De Mensuris. Divers ouvrages. Mem. de l'Acad. Roy. des Sciences, 1666–1699, Tome 6, pp. 532–549. Paris, 1730.

2.—HIRE; M. DE LA. Comparaison du pied antique Romain a celui du Châtelet de Paris, avec quelques remarques sur d'autres mesures. Mem. de l'Acad. Roy. des Sciences, 1714, pp. 394–400. Paris, 1717.

3.—MAUPERTUIS. La figure de la terre, déterminée par les observations de MM. de Maupertuis, Clairaut, Camus, le Monnier, * * * Outhier, * * * Celsius, * * * faites par ordre du Roy au cercle polaire. Paris, 1738. 16mo., pp. xxviii + 184.

4.—CASSINI DE THURY. Sur la propagation du son. (On p. 135 has statement respecting standards of length exchanged between the French Academy and the English Royal Society.) Mem. de l'Acad. Roy. des Sciences, 1738, pp. 128–146. Paris, 1740.

5.—Dégré du méridien entre Paris et Amiens, déterminé par la mesure de M. Picard et par les observations de MM. de Maupertuis, Clairaut, Camus, le Monnier, * * * Paris, 1740, 16mo, pp. lvj + 116.

6.—GRAHAM; GEORGE. An account of the proportions of the English and French measures and weights, from the standards of the same, kept at the Royal Society. Phil. Trans., 1742, pp. [185–188].

7.—GRAHAM; GEORGE. An account of a comparison lately made by some gentlemen of the Royal Society, of the standard of a yard, and the several weights lately made for their use; with the original standards of measures and weights in the Exchequer, and some others kept for public use, at Guild-hall, Founders-hall, the Tower, etc. Phil. Trans., 1743, pp. [541–556].

8.—CASSINI DE THURY. La meridienne de l'observatoire royal de Paris, vérifiée dans toute l'étendue du royaume par de nouvelles observations: Paris, 1744. 8vo, pp. 292 + ccxxxvj.

9.—**CONDAMINE; M. DE LA.** Nouveau projet d'une mesure invariable, propre à servir de mesure commune à toutes les nations. Mem. de l'Acad. Roy. des. Sciences, 1747, pp. 489–514. Paris, 1752.

10.—**BOUGUER, CAMUS, CASSINI DE THURY & PINGRÉ.** Operations faites par ordre de l'Académie pour mesurer l'intervalle entre les centres des Pyramides de Villejuive & de Juvisy, &c. Mem. de l'Acad. Royale des Sciences, 1754, pp. 172–186. Paris, 1759.

11.—1758. Report from the Committee appointed to inquire into the original standards of weights and measures in this Kingdom, and to consider the laws relating thereto. (Agreed to by the House June 2, 1758.) Printed on pp. 411–451 of Reports from Committees of the House of Commons, which have been printed by order of the House, and are not inserted in the Journals. Reprinted by order of the House. Vol. 2. (June 10, 1737, to May 21, 1765). Folio, 16¾″ × 10¾″. pp. 468.

12 —1759. Report from the Committee appointed (upon the first day of Dec., 1758) to inquire into the original standards of weights and measures in this Kingdom, and to consider the laws relating thereto. (Agreed to by the House April 12, 1759.) Printed on pp. 453–463 of Reports from Committees of the House of Commons, which have been printed by order of the House, and are not inserted in the Journals. Reprinted by order of the House. Vol. 2. (June 10, 1737, to May 21, 1765). Folio, 16¾″ × 10¾″. pp. 468.

13.—**MASKELYNE; Rev. NEVIL** (Ast. Royal). The length of a degree of latitude in the province of Maryland and Pennsylvania, deduced from the foregoing operations (by Messrs. Chas. Mason and Jeremiah Dixon); by the Astronomer Royal. Phil. Trans., 1768, pp. 323–325.

14.—**CONDAMINE; M. DE LA.** Remarques sur la toise-étalon du Châtelet, et sur les diverses toises employées aux mesures des degrés terrestres & à celle du pendule à secondes. Mem. de l'Acad. Roy. des Sciences, 1772, 2ᵉ partie. pp. 482–501. Paris, 1776.

15.—**ROY; Maj.-Gen. WM.** An account of a measurement of a base on Hounslow Heath. (Four large folding plates.) Phil. Trans., 1785, pp. 385–480.

16.—**LA LANDE; JEROME LE FRANÇAIS.** De la grandeur et de la figure de la terre. Astronomie, Tome 3, pp. 1–47. (3d edition; Paris, 1792.)

17.—**BORDA, COULOMB, LEGENDRE, LAPLACE, PRONY, et BRISSON.** Rapport sur la vérification de l'étalon qui doit servir pour la fabrication des poids républicains. Annales de Chimie, Paris, 1797, Tome 20, pp. 269–273.

18.—**SHUCKBURGH EVELYN; Sir GEO.** An account of some endeavors to ascertain a standard of weight and measure. Phil. Trans., 1798, pp. 133–182.

19.—**Van-Swinden, Trallès, Laplace, Legendre, Méchain, Delambre, Ciscar.** Rapport sur la détermination de la grandeur de l'arc du méridien compris entre les parallèles de Dunkerque et Barcelone, et sur la longueur du mètre qu'on en déduit. Base du Système Métrique Décimal, Tome 3, pp. 415–433. Paris, 1810. 4to.

20.—**Kater**; Capt. **Henry.** An account of experiments for determining the length of the pendulum vibrating seconds in the latitude of London. Phil. Trans., 1818, pp. 33–102.

21.—**Kater**; Capt. **Henry.** On the length of the French mètre estimated in parts of the English standard. Phil. Trans., 1818, pp. 103–109.

22.—Experiments relating to the pendulum vibrating seconds of time in the latitude of London. 41 pp. (E. P. P.) Accounts and papers. Session, 27 Jan.–10 June, 1818. Vol. 15. Folio, 13¼″ × 8½″. This is a verbatim reprint of Capt. Kater's papers in the Phil. Trans., 1818, pp. 33 to 109.

23.—**Banks, Clerk, Gilbert, Wollaston, Young,** and **Kater.** First Report of the Commissioners appointed to consider the subject of weights and measures. (Dated 24 June, 1819) 17 pp. (E. P. P.) Report from Commissioners. Session, 21 Jan.–13 July, 1819. Vol. 11. Folio, 13¼″ × 8½″.

24.—**Clerk, Gilbert, Wollaston, Young & Kater.** Second Report of the Commissioners appointed by His Majesty to consider the subject of weights and measures. (Dated July 13, 1820) 40 pp. (E. P. P.) Reports from Commissioners. Session, 21 April to 23 Nov. 1820. Vol. 7. Folio, 13¼″ × 8½″.

25.—**Clerk, Gilbert, Wollaston, Young & Kater.** Third Report of the Commissioners appointed by His Majesty to consider the subject of weights and measures. (Dated Mar. 31, 1821) 6 pp. (E. P. P.) Reports from Committees. Session, 23 Jan. to 11 July, 1821. Vol. 4. Folio, 13¼″ × 8½″.

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27.—**Kater**; Capt. **Henry.** An account of the comparison of various British standards of linear measure. Phil. Trans., 1821, pp. 75–94.

28.—Report from the Select Committee of the House of Lords * * * (on petition from Glasgow relative to) * * * the bill entitled "An act for ascertaining and establishing uniformity of weights and measures" * * * together with the minutes of evidence taken before said Committee. (Dated 2 Mar., 1824) 35 pp. (E. P. P.) Reports from Committees. Session, 3 Feb. to 25 June, 1824. Vol. 7. Folio, 13″ × 8½″.

29.—**Kater**; Capt. **Henry.** An account of the construction and adjustment of the new standards of weights and measures of the United Kingdom of Great Britain and Ireland. Phil. Trans., 1826, part 2, pp. 1-52.

30.—**Kater**; Capt. **Henry**. On errors in standards of linear measure, arising from the thickness of the bar on which they are traced. Phil. Trans., 1830, pp. 359-381.

31.—**Kater**, Capt. **Henry**. An account of the construction and verification of a copy of the imperial standard yard made for the Royal Society. Phil. Trans., 1831, pp. 345-347.

32.—Minutes of evidence taken before the Select Committee on bill to amend and render more effectual two acts of the 5th and 6th years of the reign of his late Majesty King George the 4th, relating to weights and measures. 67 pp. (E. P. P.) Reports from Committees. 1834. Vol. 18, part 1. Folio, 13″ × 8½″.

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34.—**Baily**; **Francis**. Report on the new Standard Scale of this (the Royal Astronomical) Society. (Gives also a history of English standards of length.) Mem. Roy. Ast. Soc., 1836. Vol. 9, pp. 35-184.

35.—**Airy**, **Baily**, **Bethune**, **Herschel**, **Lefevre**, **Lubbock**, **Peacock**, **Sheepshanks**. Report of the Commissioners appointed to consider the steps to be taken for restoration of the standards of weight and measure. (Dated 21 Dec., 1841) 106 pp.. (E. P. P.) Reports from Commissioners. Session, 3 Feb.-12 Aug., 1842. Vol. 25. Folio.

36.—**Kelly**; **Patrick**. The universal cambist: being a full and accurate treatise on the exchanges, coins, weights, and measures of all trading nations and their colonies. By P. Kelly, LL.D. 2nd edition. London, 1835. 2 vols., 4to. Vol. 1, pp. xl + 422; Vol. 2, pp. xxiv + 380.

37.—**Yolland**; Capt. **Wm.** An account of the measurement of Lough Foyle base in Ireland, with its verification and extension by triangulation; etc., etc. Pub. by order of the Hon. Board of Ordnance. London, 1847. 4to, pp. 154 + [117].

38.—**Airy**, **Rosse**, **Wrottesley**, **Lefevre**, **Lubbock**, **Peacock**, **Sheepshanks**, **Herschel**, **Miller**. Report of the Commissioners appointed to superintend the construction of new parliamentary standards of length and weight. (Dated March 28, 1854) 23 pp. (E. P. P.) Reports from Commissioners. Session, 31 Jan.-12 Aug., 1854. Vol. 19. Folio, 13″ × 8½″.

39.—Abstract of "Report of the Commissioners appointed to consider the steps to be taken for restoration of the standards of weight and measure." 16 pp. (E. P. P.) Reports from Commissioners. Session, 12 Dec., 1854-14 Aug., 1855. Vol. 15. Folio, 13″ × 8½″.

40.—**Miller**; Prof. W. H. On the construction of the new imperial standard pound, and its copies of platinum; and on the comparison of the imperial standard pound with the Kilogramme des Archives. Phil. Trans., 1856. pp. 753-946.

41.—AIRY; Sir GEO. B. Account of the construction of the new national standard of length, and of its principal copies. Phil. Trans., 1857. pp. 621-702.

42.—CLARKE; Capt. A. R. Comparisons of the standards of length of England, France, Belgium, Prussia, Russia, India, Australia, made at the Ordnance Survey Office, Southampton. Published by order of the Secretary of State for War. London, 1866. 4to, pp. 287.

43.—CHISHOLM; HENRY WILLIAMS. Seventh annual report of the Warden of the Standards on the proceedings and business of the standard weights and measures department of the Board of Trade. For 1872-3. 8vo, pp. 105. (Contains: Appendix IV.—Account of the standard weights and measures of Queen Elizabeth. pp. 10-26: Appendix V.—Account of the standard weights and measures of Henry VII. pp. 27-34: Appendix VI.—New standard weights and measures constructed and legalised from the reign of Queen Elizabeth to George IV. pp. 35-40.) (E. P. P.) Reports from Commissioners. Session, 6 Feb.-5 Aug., 1873. Vol. 38.

44.—CHISHOLM; H. W. On the science of weighing and measuring, and standards of measure and weight. By H. W. Chisholm, warden of the standards. 16mo, pp, xvi + 192. London: Macmillan & Co. 1877.

45.—HILGARD; JULIUS E. Report on the comparison of American and British standard yards. Report of the Superintendent of the U. S. Coast Survey, 1877. Appendix No. 12, pp. 148-181. 4to.

46.—WOLF; C. Recherches historiques sur les étalons de poids et mesures de l'Observatoire, et les appareils qui ont servi a les construire. Annales de l'Observatoire de Paris. Mémoirs, Tome 17, pp. C.1-C.78. (Published in 1883.)

47.—WOLF; C. Résultats des comparaisons de la toise du Pérou au mètre international, exécutées au Bureau international des Poids et Mesures par M. Benoît. Comptes Rendus, 3 Avril, 1888. Tome 106. pp. 977-982.

48.—Copies "of a letter from the Comptroller General of the Exchequer to the Treasury, dated 3 June, 1863, transmitting a report on the Exchequer standards of weight and measure, dated 27 April, 1863, by Mr. Chisholm, chief clerk in the office of the Comptroller General of the Exchequer; together with a copy of his report:" and, of a memorandum by the Astronomer Royal, dated 24 April, 1862, containing notes for the Committee on Weights and Measures, 1862. 51 pp. (Contains a complete descriptive list of all the old Exchequer standards; a discussion on the moneyer's pound; and a history of English legislation on weights and measures.) (E. P. P.) Trade (Generally). Session, 4 Feb.-29 July, 1864. Vol. 58. Folio.

49.—Annual reports of the Warden of the Standards on the proceedings and business of the standard weights and measures department of the Board of Trade. 8vo. (Printed as English Parliamentary Papers, and contained in the volumes of "Reports from Commissioners.")

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10th	1875-6	68	1876, Vol. 26.
11th	1876-7	12	1877, Vol. 33.
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50.—Reports of the Commissioners appointed to inquire into the condition of the Exchequer (now Board of Trade) standards. Presented to both Houses of Parliament by command of Her Majesty. Folio. (Printed as English Parliamentary Papers, and contained in the volumes of "Reports from Commissioners.")

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2d	3 April, 1869	133	1868-9, Vol. 23.
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4th†	21 May, 1870	438	1870, Vol. 27.
5th	3 August, 1870	265	1871, Vol. 24.
General Index		101	1873, Vol. 38.

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* On the abolition of troy weight.
† On the inspection of weights and measures, etc.

51.—AIRY; Sir GEO. B. Extracts of papers, printed and manuscript, laid before the Commission appointed to consider the steps to be taken for restoration of the standards of weight and measure, and the subjects connected therewith. Arranged by G. B. Airy, Esq., Astronomer Royal. Printed by order of the Lords Commissioners of the Treasury. London, 1840. 4to, 155 pp. (Consists of a vast number of brief extracts giving the opinions of many experts upon various points connected with the construction and use of standards of weight and measure, and the advantages and disadvantages of various systems of such standards.)

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53.—ADAMS; JOHN QUINCY. Report upon weights and measures, by John Quincy Adams, Secretary of State of the United States. Prepared in obedience to the resolution of the Senate of the 3d of March, 1817. Washington: printed by Gales & Seaton. 1821. 8vo, pp. 245. (Contains report of F. R. Hassler on comparisons of English and French measures. pp. 153-170.)

54.—ALEXANDER; J. H. Report (made to the governor of Maryland) on the standards of weight and measure for the State of Maryland; and on the construction of the yard-measures. Baltimore, Dec. 13, 1845. 8vo, pp. iv + 213.

55.—HASSLER; FERDINAND RODOLPH. Comparison of weights and measures of length and capacity. Reported to the Senate of the United States by the Treasury Department in 1832, and made by Ferd. Rod. Hassler. 22d Congress, 1st Session, Ho. of Reps., Doc. No. 299. Washington, 1832. 8vo, 122 pp., with 4 folding plates. (Contains a paper by Trallès giving important details, not published elsewhere, respecting the original iron meters of the Commission des Poids et Mesures of 1799.)

56.—HASSLER; F. R. Report from the Secretary of the Treasury, transmitting the report of F. R. Hassler, superintendent of the Coast Survey, and of the fabrication of standard weights and measures. 25th Congress, 2d Session, Senate, Doc. No. 79. Washington, 1837. 8vo, 16. pp. (Explains method adopted for determining subdivisions of the troy pound.)

57.—HASSLER; F. R. Report upon the standards of the liquid capacity measures of the system of uniform standards for the United States; with description of a new original barometer, and of the balance for adjusting the half bushels by their weight of distilled water. By F. R. Hassler. 27th

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59.—BACHE; Prof. ALEXANDER D. Report to the Treasury Department on the progress of the work of constructing standards of weights and measures for the custom-houses, and balances for the States, and in supplying standard hydrometers to the custom-houses, from 1 Jan., 1848, to 31 Dec., 1856. 34th Congress, 3d Session, Senate, Ex. Doc. No. 27. Washington, 1857. 8vo, 218 pp. with 6 folding plates. (Contains descriptions of yard dividing engine, and various comparators.)

60.—ROGERS; Prof. W. A. On the present state of the question of standards of length. (Contains a bibliography.) Proceed. Amer. Acad. of Arts and Sciences, 1879–80. Vol. 15. pp. 273–312.

61.—ROGERS; Prof. W. A. On two forms of comparators for measures of length. 8vo, 12 pp. American Quarterly Microscopical Journal, April, 1879.

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63.—ROGERS; Prof. W. A. An examination of the standards of length constructed by the Société Génevoise. Proceed. Amer. Acad. of Arts and Sciences, 1884–'5. Vol. 20, pp. 379–389. 8vo.

64.—ROGERS; Prof. W. A. A study of the centimeter marked "A," prepared by the U. S. Bureau of Weights and Measures for the Committee on Micrometry. 8vo, 23 pp. Proc. Amer. Society of Microscopists. Vol. 32, p. 184.

65—ROGERS; Prof. WM. A. On a practical solution of the perfect screw problem. 8vo, 44 pp. Trans. Amer. Soc. of Mechanical Engineers. Vol. 5.

66.—ROGERS; Prof. W. A. A critical study of the action of a diamond in ruling lines upon glass. 8vo, 17 pp. Proc. Amer. Society of Microscopists. Vol. 32, p. 149.

67.—Travaux et mémoires du Bureau International des Poids et Mesures, publiés sous l'autorité du Comité International, par le Directeur du Bureau. Paris. 4to. Tome 1, 1881, 391 pp.; T. 2, 1883, 413 pp.; T. 3, 1884, 348 pp.; T. 4, 1885, 421 pp.; T. 5, 1886, 416 pp.

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